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Modelling tendon excursions and moment arms of the finger flexors: Anatomic fidelity versus function

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ABSTRACT

A detailed musculoskeletal model of the human hand is needed to investigate the pathomechanics of tendon disorders and carpal tunnel syndrome. The purpose of this study was to develop a biomechanical model with realistic flexor tendon excursions and moment arms. An existing upper extremity model served as a starting point, which included programmed movement of the index finger. Movement capabilities were added for the other fingers. Metacarpophalangeal articulations were modelled as universal joints to simulate flexion/extension and abduction/adduction while interphalangeal articulations used hinges to represent flexion. Flexor tendon paths were modelled using two approaches. The first method constrained tendons with control points, representing annular pulleys. The second technique used wrap objects at the joints as tendon constraints. Both control point and joint wrap models were iteratively adjusted to coincide with tendon excursions and moment arms from a anthropometric regression model using inputs for a 50th percentile male. Tendon excursions from the joint wrap method best matched the regression model even though anatomic features of the tendon paths were not preserved (absolute differences: mean < 0.33 mm, peak < 0.74 mm). The joint wrap model also produced similar moment arms to the regression (absolute differences: mean < 0.63 mm, peak < 1.58 mm). When a scaling algorithm was used to test anthropometrics, the scaled joint wrap models better matched the regression than the scaled control point models. Detailed patient-specific anatomical data will improve model outcomes for clinical use; however, population studies may benefit from simplified geometry, especially with anthropometric scaling.

1. Introduction

The need to quantify flexor tendon motion is found in the common pathology of fibrosis of the tenosynovium in patients with tendinopathies and carpal tunnel syndrome (Barr et al., 2004), as well as posttraumatic and postoperative flexor tendon adhesions (Strickland, 2005). Changes to the subsynovial connective tissue (SSCT) suggest that shear forces from differential tendon motion are involved in injury development (Ettema et al., 2006). Fibrosis of the SSCT influences tendon gliding in the carpal tunnel, resulting in adherence or dissociation between the flexor tendons and the tenosynovium (Ettema et al., 2008), and might decrease range of motion. Flexor tendon gliding changes may increase frictional forces even further, resulting in a vicious cycle of degradation (Ettema et al., 2008; 2006), and have been shown to increase when one finger is moved alone compared to moving all fingers in unison (Zhao et al., 2007). While friction between the flexor tendons and the annular pulleys may decrease muscular load for static and eccentric contractions (Schöffl et al., 2009; Schweizer et al., 2003; Walbeehm and McGrouther, 1995), tendon frictional work was found to be highly correlated with workplace distal upper extremity injuries (Moore et al., 1991).

Flexor tendon excursions have been assessed *in vitro* (An et al., 1983; Armstrong and Chaffin, 1978; Ugbolue et al., 2005; Yamaguchi et al., 2008) and *in vivo* using ultrasound (Lopes et al., 2011; Oh et al., 2007; Yoshii et al., 2009). Armstrong and Chaffin (1978) developed linear regression equations to predict tendon excursions of flexors digitorum profundus (FDP) and superficialis (FDS) based on joint angles and thicknesses from cadavers. Their data were also used to assess Landsmeer's (1961) geometric models of tendon–joint interaction (see Keir and Wells, 1999, for an assessment of moment arms in Landsmeer's models). Similar methods have been used to examine index finger tendon excursions and moment arms (An et al., 1983) as well as differential motion between the flexor tendons and median nerve in the carpal tunnel (Ugbolue et al., 2005; Yamaguchi et al., 2008).

The regression model of Armstrong and Chaffin (1978) has been used to evaluate injury risk during keyboarding (Sommerich et al.,

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